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Argonne National Laboratory

THE ARGONNE THERMAL SOURCE REACTOR

by

Roland J. Armani

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Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois

THE ARGONNE THERMAL SOURCE REACTOR

by

Roland J. Armani

Reactor Engineering Division

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ABSTRACT

The Argonne Thermal Source Reactor is a highly enriched, light-water-moderated thermal reactor. Movable shielding allows complete access to one face of the core. There is ready access to the central and 2 peripheral core locations, and it is possible to thrust samples with small reactivity effects into these locations. The reactor has been approved for operation at 10 kw. Design and construction details are described to aid present and potential users of this facility.

I. INTRODUCTION

When the ZPR-I critical experiments were terminated, the reactor vessel was modified for use as a neutron source to drive a fast exponential experiment. This experiment is described in a hazards summary report submitted to the Atomic Energy Commission.[1] Since this was the fourth Argonne zero-power experiment, the reactor was named ZPR-IV. After completion of the fast exponential experiment, the source reactor was again modified and moved to a new wing of the critical facilities building. Most of the hardware was replaced, but the physics and nuclear safety aspects remained the same. The ZPR-IV hazards report was adopted with the addition of two cover letters which described the modifications, and the reactor was renamed ZPR-IV'.[2]

During the spring and summer of 1960, the core tank was redesigned and replaced due to extensive corrosion which had taken place. At the same time the instrumentation was modernized, maintenance and repair work was done where necessary, and several other modifications were made. To indicate that the reactor is used primarily as a source of neutrons, it was renamed the Argonne Thermal Source Reactor (ATSR) upon completion of the modernization and maintenance work. This report describes the ATSR in its present state.

II. DESCRIPTION OF THE REACTOR

A general view of the ATSR facility is shown in Fig. 1. Reactor instruments, exclusive of pre-amplifiers, are located in the control console. The reactor is located in a room 4.27 m high, 12.19 m long, and 7.92 m wide, called the "assembly room." It is separated from the control room by a 2-foot-thick monolithic concrete wall plus a 1-ft-thick masonry wall. Normal access is limited to the door marked A in Fig. 1. Emergency exit may be accomplished through door B, which may be opened from the inside only. Door C is a freight door which is normally locked except for the movement of large or heavy equipment. Shadow shield walls are provided near door A to reduce scattered-neutron background from the reactor. Both doors B and C are connected to the laboratory alarm system and are equipped with security seals.

The ATSR is a highly enriched (93.2% U^{235}), light-water-moderated reactor capable of operating at 10 kw for sustained periods. The core tank, which contains the fuel elements, water moderator, and reflector, is located inside a large shield tank. In order to provide a high-intensity source of neutrons for external experiments, the core tank is fastened to the center of one side of the shield tank, this being called the "front face" or "leakage face." Three access holes to the core from the top of the shield tank are provided for addition or removal of fuel and for experimental purposes. A large beam hole is located on the side of the reactor. Experiments may be conducted on the leakage face, in the beam hole or in the core by means of the access holes.

Figure 2 is a cutaway view of the reactor. Fuel elements are positioned in the core tank by an aluminum shroud. Control rods and safety rods are driven into and out of the core from the top, and the startup source is driven to the edge of the core on the side opposite the beam hole. Water is pumped from the dump tank located in a pit next to the reactor, through a 15.2-cm dump line to the core, and returns to the dump tank by way of an overflow pipe above the core, providing continuous circulation of reactor water.

Shielding for the core is provided on all faces except the leakage face by water and lead. Normally, the shield water is borated (with boric acid) so that it is necessary to avoid mixing core and shield water. A removable tank filled with shielding water is located over the top of the core to provide shielding in this direction. Re-entrant channels in this tank provide the necessary guides for the control rods, safety rods, and fuel access holes. Two thimbles are provided for neutron detectors.

A. Core Assembly

The core assembly consists of 2 tanks and a collar as shown in Fig. 3. The lower core tank contains the fuel elements, which are positioned in a matrix by an aluminum shroud. Twenty-five vertical compartments are provided in a square array, 5 across and 5 deep, each compartment being 7.6 x 7.6 cm. The fuel elements which are used in these compartments are BORAX-type fuel elements. The 2 control rod guides are welded inside the matrix, and the 2 safety-rod guides are welded to the outside of the matrix. A 15.2-cm-diameter pipe is attached to the bottom of the lower core tank. It goes through a 15.2-cm, air-driven butterfly valve and into a 950-liter dump tank in the pit alongside the reactor.

A collar is fastened to the top of the lower core tank. A shield tank is located inside of the collar in such a manner that the top of the shield tank is fastened to the top of the collar. Figure 3 will clarify the assembly of these tanks. Guides for safety and control rods, and access holes are attached to the bottom of the shield tank. Reactor water rises into the guides, but not into the shield tank, which is normally filled with borated water.

Each BORAX fuel element consists of 10 curved, aluminum-clad, uranium-aluminum alloy plates welded to aluminum side plates to form a 7.6 x 7.6 x 67.9-cm assembly. The uranium-aluminum alloy is 0.0635 cm thick and the cladding is 0.0444 cm thick. The 2 end plates are longer, but they have the same active length and width, and the same amount of uranium as the other 8 plates. Figure 4 is a drawing of a ten-plate BORAX fuel assembly. Each assembly contains an average of 157 gm of U^{235}, with each plate containing 15.7 gm. The critical mass varies between 2.5 and 3.5 kg, depending upon the experimental materials on the leakage face and inside the core, so that 16 to 22 fuel elements are necessary to achieve a critical mass. The fuel elements which are accessible from the top of the reactor contain only 4 welded fuel plates with space provided for inserting 6 additional plates. Figure 5 is a top view of ATSR showing the fuel matrix and positions of the control and safety rods. The numbers in the matrix indicate the number of fuel plates in the elements for a particular loading (November 1960) with no reflector on the leakage face. The 4 corners of the matrix do not contain fuel elements but are filled with graphite plugs having the same dimensions as a fuel element.

The fuel matrix is positioned against the leakage face in the core tank and equally spaced from the other 5 faces. The core tank is completely filled with moderator so that there are 10.2 cm of light water reflector on all sides of the fuel matrix except at the leakage face.

As was previously mentioned, the safety rods are outside the core matrix, and the control rods are inside the matrix. In order to provide room for the control rods, 2 of the fuel elements contain 8 welded fuel plates rather than 10. The control-rod guide is an aluminum sleeve which extends from the bottom of the shield tank to the bottom of the core tank and directly through the core matrix. Figure 5 shows the position of the control and safety rods relative to the leakage face. The shaded matrix holes are those accessible from the top.

The central access hole normally contains no fuel. This is usually occupied by a void tube ranging in diameter from 2.54 to 7.62 cm. An increase in void-tube diameter increases the reactivity of the system. (The dependence of reactivity on void tube size is given in Fig. 23.)

B. Safety Rods

The 2 safety rods used in ATSR are made of 0.152-cm-thick cadmium, 24.45 cm wide and 71.12 cm long. They are clad with 0.318-cm stainless steel and give a total shutdown of 1.8% Δk.

The safety-rod drive units[3] were originally designed and used for operation with ZPR-I. Except for redesign of the position-indicator mechanisms, these rod-drive units are the same as those used in several critical experiments at Argonne during the past 10 years.

A 0.318-cm-diameter cable attached to the safety rod passes through a pulley system to a drum which is coupled to a gear motor through an electromagnetic clutch (see Fig. 6). The drum is mounted on ball bearings and is free to rotate when the clutch is de-energized automatically at scram, by power failure, or by the operator. With the clutch de-energized, the control rod falls with an acceleration of about 0.75 g. The rod is decelerated smoothly when very near the bottom position by bringing a Houdi-type shock absorber into action as a snubber. The shock absorber is coupled with the drum by a cable loop system, one end of which winds up while the other unwinds as the drum turns. When one end is unwound, it starts rewinding so that both ends of the cable are winding up on the drum and the loop shortens, pulling the shock-absorber arm back. The rod comes to rest fully inserted. The cable is capable of snubbing the rod without permanent set after a free fall of 1.5 m, even if the shock absorber fails to operate. Mechanical stops prevent the rod from striking the bottom of the core tank and also from being withdrawn beyond the rod guide. Limit switches control the power to and direction of rotation of the motor. Rod position is transmitted from the unit and received at the control console by coupled synchros.

The drive motor is $\frac{1}{30}$ hp and is capable of operating at various speeds from a 90-v, dc power supply. The gear drive allows a maximum rod withdrawal speed of 1.4 cm/sec. The drive circuits are interlocked so that only one rod, as determined by a selector switch, can be withdrawn at a time.

C. Control Rods

The 2 control rods are made of 0.102-cm cadmium, 5.56 cm wide and 71.1 cm long. The cadmium is painted with aluminum paint to retard corrosion and is sandwiched between two 0.16-cm aluminum sheets. The worth of each rod is dependent upon the core loading, but the value is about 1.5% $\Delta k/k$ for each control rod.

The control rod drives are of the rack and pinion type (see Fig. 7). A 48-pitch rack is mounted on a 0.95-cm-diameter, Type 304 stainless steel tube and is driven by a Bodine gear reduction motor. The control rod is fastened to the end of the Type 304 stainless steel tube by means of a ball-joint connector, allowing the control rod to travel through the guide without binding. The drive motor is a 27-v, dc, variable-speed, reversible motor, and at maximum speed will drive the control rod at 1 cm/sec. At scram, the control rods are driven into the core in contrast with the safety rods, which fall freely. Limit switches control the power to the drive motors to prevent driving the control rods against the upper or lower mechanical stop. Rod position is transmitted from the unit to the console by coupled synchros. The drive circuits are interlocked so that the rods may be withdrawn only when the assembly room door is closed, the dump valve is closed, the core tank is filled with moderator, the safety rods are fully withdrawn, and the low-level flux monitor is activated by the presence of the startup source. In addition, only one rod at a time may be withdrawn as determined by a selector switch at the console.

D. Startup Source

In order for the neutron detectors to observe some flux before criticality is achieved, a source of neutrons is introduced at the side of the core. The source is a plutonium-beryllium alloy containing 80.98 gm of plutonium. It has a calibrated neutron output of 8.48×10^6 neutrons/sec. Figure 8 shows the position of the source with respect to the core in both the "source in" and "source out" position. The source is driven in and out by an air-cylinder drive located outside the shield tank.

Since the source contains a fissionable isotope, it contributes a positive reactivity effect to the reactor. A measurement of this positive reactivity effect showed the value to be $(1.48 \pm 0.16) \times 10^{-4}\ \Delta k/k$.

E. Dump Valve

The dump valve, located in the 15.2-cm line issuing from the bottom of the core tank, is a butterfly valve driven by a fast-acting, rotary air cylinder manufactured by Carter Controls, Lansing, Illinois. This air cylinder provides a rotary motion of a predetermined number of degrees by the motion of a piston moving along a helical shaft. It is designed so that air pressure can be applied to only one side of the rotary air cylinder at a time, assuring positive action. It is connected as described in the air flow system and in Figs. 15 and 16. Figure 9 is a photograph of the disassembled dump valve.

F. Shielding

In order that the ATSR be flexible enough to accommodate many types of experiments, and since the reactor is located in a well-shielded room normally used by unshielded critical assemblies, no effort was made to provide a large biological shield. Shielding is provided on 3 sides and the bottom of the core tank by 10.2 cm of borated water, 15.3 cm of lead, and more borated water, as shown in Fig. 2. The top is shielded by the borated water in the upper shield tank. The outer shield tank is 1.83 m wide, 2.44 m high, and 1.83 m deep, so that there is a minimum of 45.7 cm of shield water at any point except the leakage face. The boron in the shield tank is in the form of boric acid with an average concentration of 10 gm/liter.

Since the neutron shield around the core tank is relatively small, there exists a large amount of neutron scatter in the assembly room from the ceiling, floor, and walls. In some cases it is necessary for an experimenter to shield equipment, which is against the leakage face, to eliminate scattered neutrons.

III. NEUTRON FLUX IN THE REACTOR

Since the ATSR is a flexible device and the neutron flux shapes may easily be changed, little information is available as to accurate, absolute measurements of thermal flux. It will be sufficient here to state that at a power level of 70 w, the thermal flux at the vertical center of the core inside a 5.08-cm void tube in the central access hole is approximately 10^{10} n/(cm^2)(sec) with a cadmium ratio of 5 for gold. On the center of the leakage face it is 10^8 n/(cm^2)(sec), and in the beam hole the value is 10^7 n/(cm^2)(sec).

IV. INSTRUMENTATION

There are 7 instrument channels used for reactor operation. A block diagram of the instrumentation is shown in Fig. 10. The locations of the various detectors are shown in Fig. 11.

There are 5 linear channels, one logarithmic channel, and one low-level flux interlock channel. Two of the linear channels (P-2 and P-6) are similar, consisting of ANL Type IC-15A, compensated B^{10}-coated ionization chambers whose output current is displayed on ANL Type CD-111 multirange amplifiers. A third channel (P-1) also uses a compensated B^{10}-coated ionization chamber as the detector, but in this case the current develops a voltage across a large resistance (10^4 to 10^{10} ohms selected at the console). The voltage is detected by means of an Applied Physics Corporation Model 30 Vibrating Reed Electrometer (VRE). Provision is made to buck out most of the dc signal read on the VRE, allowing the difference signal to be expanded, thereby increasing the sensitivity of the instrument.

Two linear, high-level trips (P-4 and P-4') are provided. Their sensitivity and location are adjusted to scram the reactor when the maximum allowable operating power level is reached. The detectors on these instruments are Pilot B plastic scintillators mounted on Du Mont 6363 photomultiplier tubes. Unlike the aforementioned neutron detectors, these high-level trips are predominantly gamma detectors. The current produced by the photomultiplier is monitored at the console.

Channel P-7 is an Argonne-designed log power and period meter. Its detector is an ANL-IC-25 compensated B^{10}-coated ionization chamber. The log power meter covers 8 decades, and the period meter indicates periods from 10 sec to infinity with an infinity-center meter.

The low-level flux interlock channel is a modified ANL, CD-129A linear current amplifier with an IC-25 ionization chamber detector. The function of this instrument is to insure that some neutron flux is present in the core before the control rods are removed. When the startup source is inserted, a predetermined minimum current is exceeded, which satisfies the low-level flux interlock channel. This is one of the several interlocks in the circuit which supplies electrical power to the control rods.

Four recorders are provided on the control console for chart display of the reactor instruments. Channels P-1, P-2, P-7 log power, and P-7 period are the recorded signals. The remaining 4 channels are displayed on panel meters.

The detectors are located in various positions with respect to the core such that there is always available at least one channel which has linear response characteristics at any power level at which the reactor is operating. The normal startup and low-level operating instrument is P-2. Its linearity extends to high power levels. The linearity of P-6 overlaps with the linearity of P-2 and remains linear to the maximum power level so that P-6 is the channel normally used at high power levels. Channel P-7 is not linear over its entire range, and because of the difficulty in reading a logarithmic scale, it is seldom used in trying to reproduce power levels. The period meter is also difficult to read, so that it is used as an indicator and safety device rather than as a means of determining the pile period accurately. Figure 12 gives the chamber output current as a function of reactor power for channels P-1, P-2, P-6, and P-7.

V. CONTROL CONSOLE

Figure 13 is a photograph of the ATSR control console. All the reactor operating instruments and necessary equipment are located on the control console. The 4 selsyn indicators show the positions of the safety and control rods. Each selsyn has 2 lights associated with it; these indicate when the rod is out or in, and a third light (select) indicates that electrical power is being supplied to that rod. Two safety-rod scram buttons are also mounted on the console. This permits dropping either safety rod independently from the other. Another safety-rod scram button, indicated in the lower right center of the photograph, permits dropping both rods simultaneously.

A bank of lights is provided to indicate to the operator whether or not the warning light outside of the building is on, the dump valve is closed, the assembly room door is closed, both safety rods are completely raised, the startup source has been inserted, a minimum flux level exists in the core, and the reactor water level has reached the top of the core tank. These are necessary conditions that must be met before startup. Other lights indicate to the operators whether or not the various resets have been satisfied, the main power and instrument power switches are closed, and the reactor water pump is operating.

Power is supplied for the rods, source, and dump valve by means of one key switch, called the Reactivity Control Switch, and the selection is made by a rotary switch called the Control Selector Switch. When a rod is being driven up or down, the speed at which it is driven is governed by the position of the Speed Control Variac.

Other indicating lights on the console show whether or not the house and standby air supplies for the dump valve operation exceed a specified minimum pressure and the dump tank heater and reactor water heat exchanger are operating. This is explained further in the air flow and water flow systems description.

A temperature indicator, which measures water temperatures at the inlet to the core and at the overflow pipe, is also on the console along with the 4 recorders which display the signals from Channels P-1, P-2, P-7 power, and P-7 period.

One hand scram button which shuts down the reactor by dropping all rods and opening the dump valve is located on the console. Three other hand scrams are also available, 2 of which are on the experimental console, and one located inside the assembly room.

VI. REACTOR CONTROL

Reactor control is accomplished by means of water, air, and electrical systems. None of the 3 systems operate independently, but for descriptive purposes this is a convenient division.

A. Water-flow System

During startup, the dump valve is closed and water is pumped into the core at a rate of approximately 34 liters/min. When the core tank is filled and the water has reached the overflow pipe, the overflow switch activates an electrically operated solenoid valve which closes the main fill line. The water is then pumped only through the bypass line (see Fig. 16) at a reduced rate of approximately 11 liters/min. A flowrate meter in the bypass line indicates the overflow rate. This means that during operation there is a constant flow of reactor water, unless the moderator pump is turned off. The experiment being performed and power level dictate whether or not the moderator is being circulated through the core.

A water-limit switch is located about 10.2 cm above the overflow switch. If for some reason the overflow pipe should become plugged and the reactor water is forced up the vent pipe, the water-limit switch will turn off the moderator pump, thereby preventing water from being pumped out of the reactor.

The 2 thermocouples are used to measure the temperature rise of the moderator as it passes through the core. At low power, there is no indication of a rise in temperature, but at higher powers (~50 w and up), the temperature rise is noticeable. The thermocouples may be used to determine power level by heat measurements, and they also indicate when cooling water should be run through the heat exchanger shown in Fig. 14.

To date the ATSR has not been operated at high enough power levels that the heat exchanger was needed.

B. Air-flow System

The source drive, dump valve, and flowrate meter are air-operated systems. Figure 15 is a diagram of the air-flow system. The system consists of the house air supply and an emergency supply provided by a tank of nitrogen gas. The 2 systems are connected together in such a manner that the failure of either supply system or loss of electrical power will remove the source from the reactor and open the dump valve. The source drive and dump valve normally operate at 1.36 atm gauge, but will operate on reduced pressures at reduced speeds. Pressure switches in both air supplies are set at 2.72 atm gauge so that when either supply drops below this point, the reactor receives a scram signal, and the operating air supply removes the startup source from the core and opens the dump valve. A check valve in the house air supply prevents the emergency supply from bleeding into the house supply and being lost to the atmosphere in the event of a rupture of the house air supply. The electrical wiring diagram of the pressure switches and solenoid valves is shown in Fig. 16.

C. Electrical System

In order to reduce operational errors as much as possible, a series of interlocks controls the order in which different operations may be performed. Figure 17, with as little detail as possible, shows how this order is controlled. Main power is supplied by means of a key switch, allowing all scram circuits to be reset. At the moment the key switch is closed, the outside warning-light system is activated and the warning bell, which rings every 60 sec in the assembly room, goes into operation. Safety rod No. 1 may now be raised. This requires one person to depress a spring-loaded pushbutton in the assembly room while another person at the console applies power to the drive motor. Closing the door of the assembly room allows the startup source to be driven to the core, the dump valve to be closed, and safety rod No. 2 to be raised. The low-level-flux interlock is satisfied by the startup source, so that power may now be applied to the moderator pump. When the water reaches the top of the core tank, the last interlock is satisfied and this allows the control rods to be raised. The Control Selector Switch and Reactivity Control Switch prevent power from being supplied to more than one of the devices simultaneously. More detailed diagrams of these circuits are given in the Appendix.

VII. REACTOR HAZARDS

There is a small chance that through equipment failure, improper operation, or sabotage an incident could occur which would damage the reactor and the building. Since the object of this report is to describe the ATSR facility and since these hazards have already been investigated and discussed previously, the discussion will not be repeated here. The reader who is interested is referred to the ZPR-IV hazards report[1] which was approved for this facility.

VIII. NUCLEAR SAFETY

The final local responsibility in the operation of the ATSR in regard to nuclear safety lies with the Director of Argonne National Laboratory. As a result, he and his staff are kept closely informed of all matters regarding nuclear safety by the Director of the Reactor Engineering Division (RED).

Close supervision is maintained through an advisory committee - the Reactor Safety Review Committee.

Approval for all significant changes in the operation of ATSR which involve nuclear safety must come from the Laboratory Director's Office (LDO). For major changes in operating conditions, approval must be obtained by the LDO from the AEC. This is accomplished through study and evaluation of proposals, and a check is made on compliance with stated procedures by periodic inspection by AEC personnel.

The storage and handling of fissionable materials, other than that used in the ATSR is supervised by LDO through a Criticality Hazards Control Committee. The committee works through the Director of RED, who appoints staff members to function as Criticality Hazards Control Representatives.

IX. SUPERVISORY AND OPERATIONAL PERSONNEL

Supervisory personnel include the Responsible Supervisor, Reactor Supervisor, and Building Superintendent. The Responsible Supervisor is responsible on a continuing basis for the safe operation of all nuclear systems and experiments within the Reactor Physics Laboratory where ATSR is located. He serves to foster a proper attitude toward nuclear safety, provides an independent judgment on unusual experiments, and checks on compliance with established procedures in the operations involving fissionable material. The Reactor Supervisor is the key figure in regard to the safe operation of ATSR and the performance of the program assigned. He must make certain that all personnel associated with the operation are thoroughly acquainted with the characteristics of the system, the operating rules, and the current program. The Building Superintendent performs an administrative function with duties as assigned by the Responsible Supervisor. These include the appointment and supervision of a non-nuclear Safety Committee, routine contacts with the Industrial Hygiene and Safety personnel, Fire Protection and Security, and others.

Operations personnel include Qualified Operators, Co-operators, and Trainees. Qualified Operators, limited to Staff and Salaried personnel, are persons who have a high degree of familiarity with the safe assembly and operation of the reactor. Their principal function is that of taking complete responsibility in regard to safety for the reactor which has been operated previously in essentially the same state. Co-operators are persons who can operate the reactor and who are familiar with the program and the standard techniques of measurements. They must have acquired a sufficient knowledge of the characteristics of the reactor and its components to recognize any malfunction or unusual behavior. Trainees are persons in their initial phase of familiarization with the reactor or program underway. Advancement to a higher level of responsibility is determined in terms of the person's demonstration that he is aware of the operating rules, the procedures for taking the system to a critical state, and the techniques used in the routine measurements.

A more detailed discussion of personnel involved with ATSR is given in the Operational Manual.[4]

X. RULES OF OPERATION

General and specific rules concerning the operation of ATSR are given in the Hazards Summary Report[1] and the Operational Manual[4] and will not be reproduced here.

APPENDIX

A number of drawings, graphs, and circuit diagrams are included here to give information about physical layout, reactor calibrations, and electrical control systems. These are useful in setting up experimental equipment in reactor calculations and in general maintenance work.

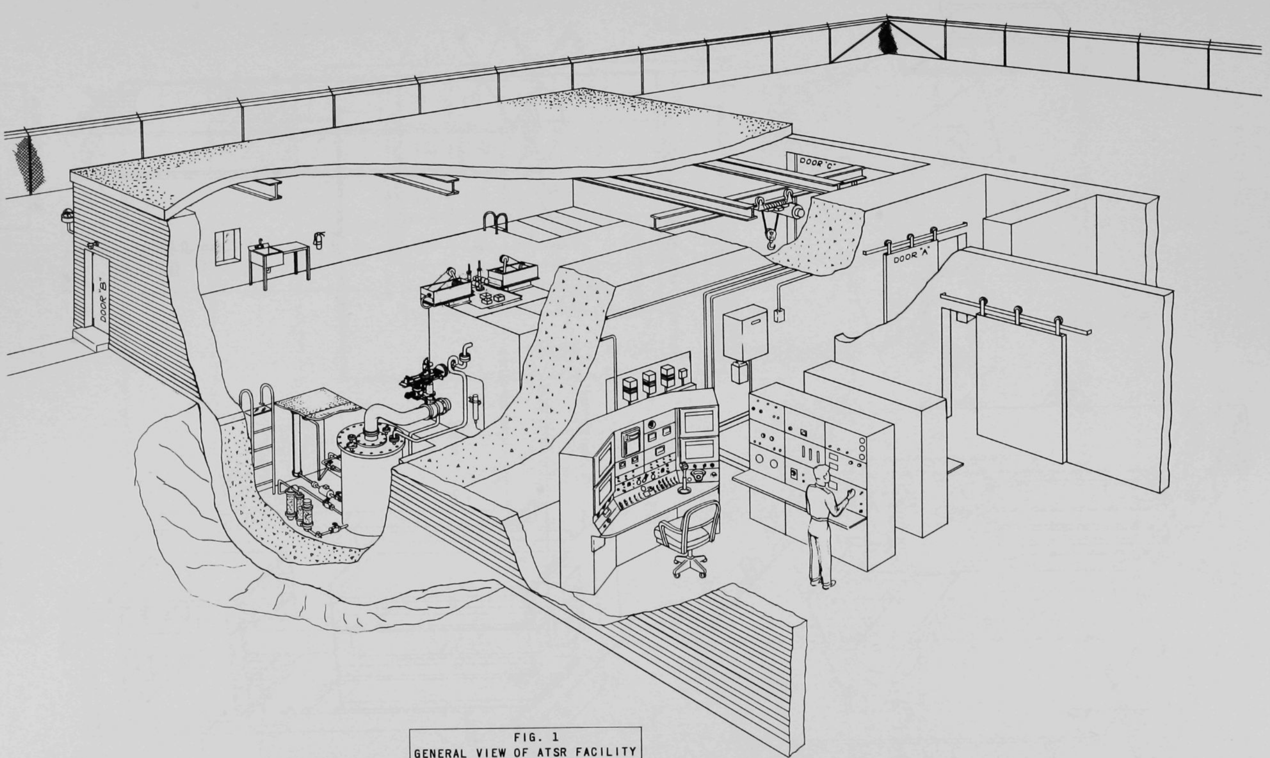


FIG. 1
GENERAL VIEW OF ATSR FACILITY

(RE-8-24524-D)

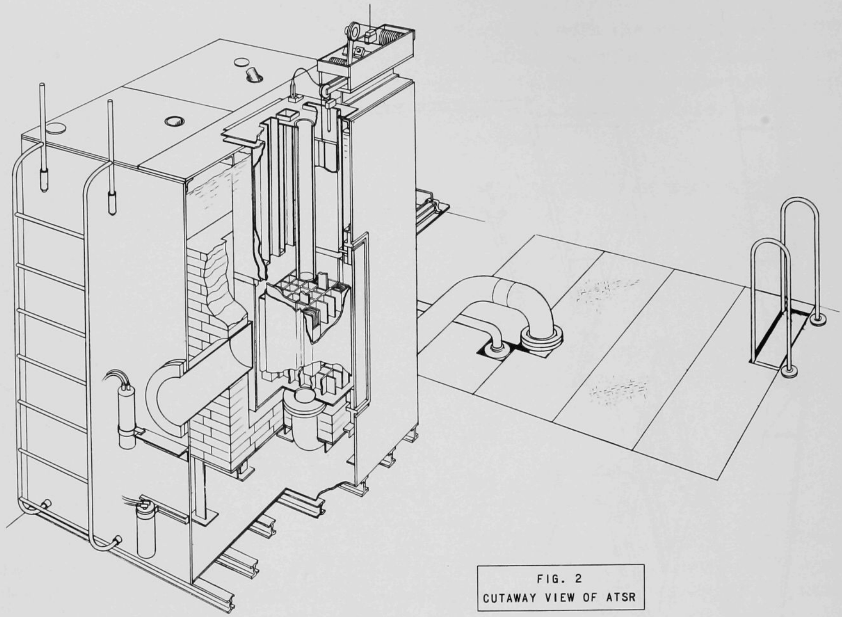


FIG. 2
CUTAWAY VIEW OF ATSR

(RE-6-24525-D)

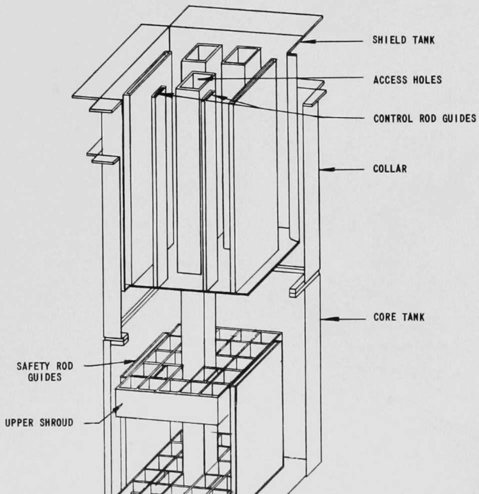
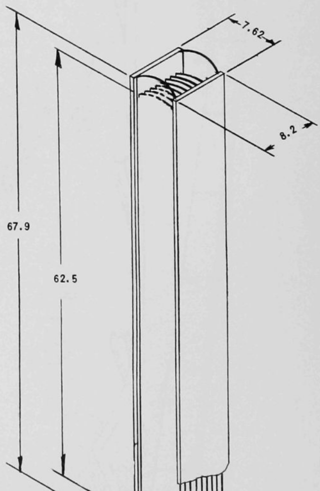


FIG. 3
CORE ASSEMBLY

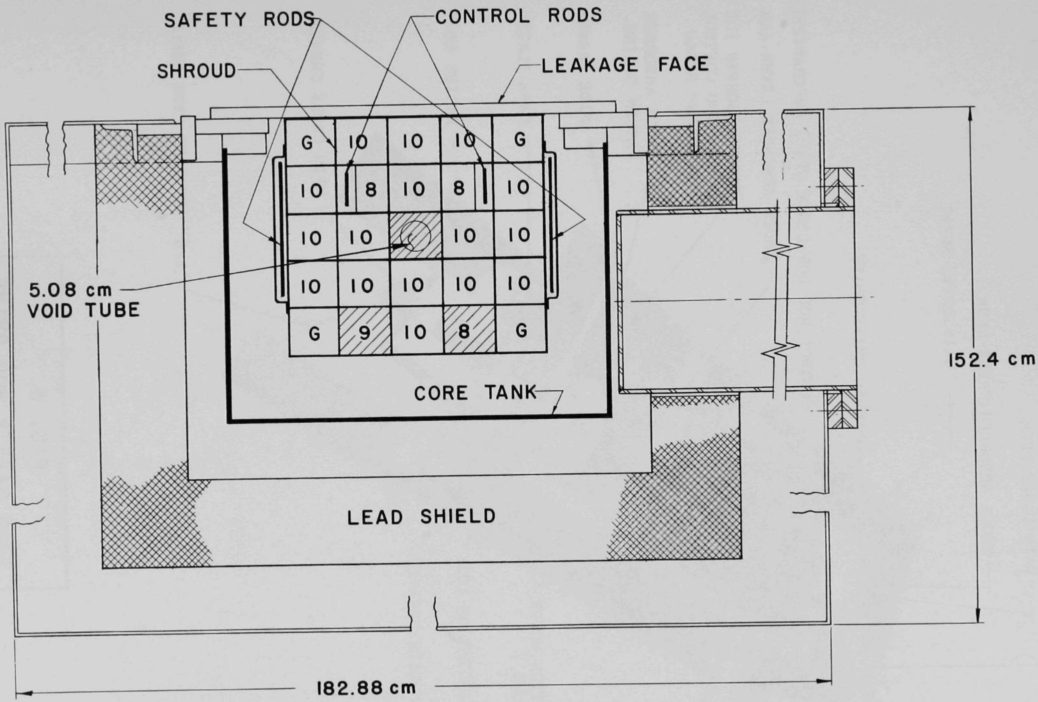
RE-8-36021-A



ALL DIMENSIONS IN cm

FIG. 4
ASTR FUEL ELEMENT

(RE-8-36016-A)



PLAN VIEW

0 5 10
SCALE

(CORE LOADING OF NOV., 1960)

FIG. 5
TOP VIEW OF ASTR

(RE-8-22391-C)

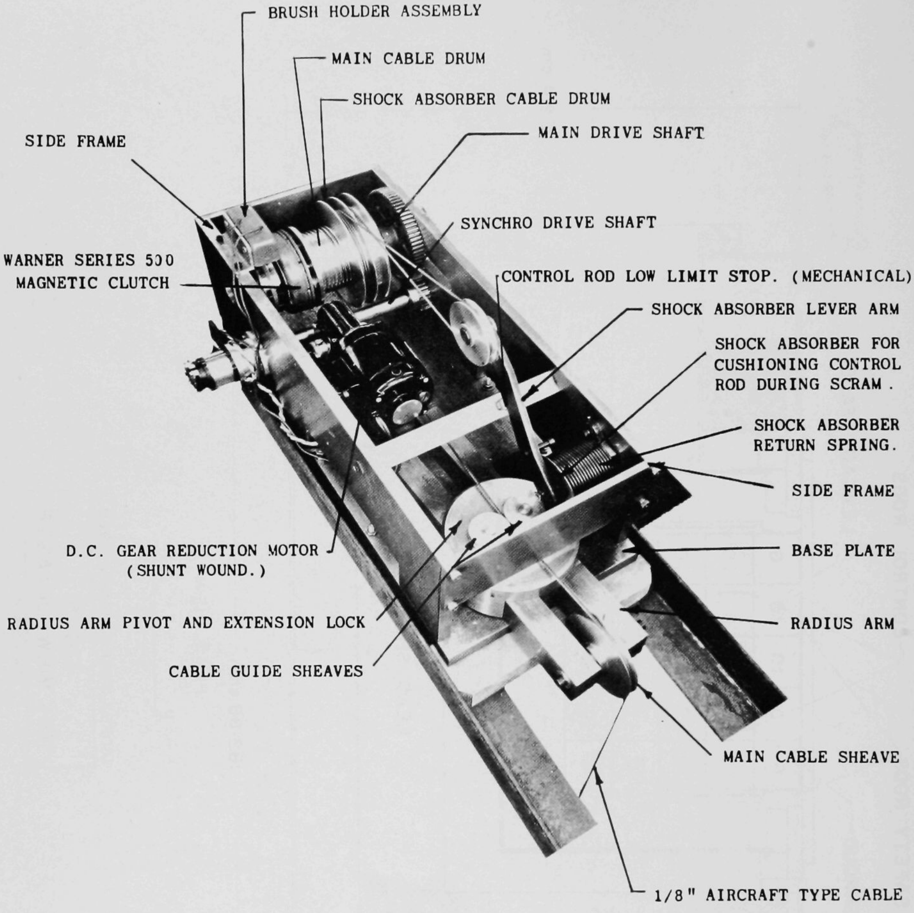


FIG. 6
ATSR SAFETY ROD DRIVE

NEG. NO. 111-5120

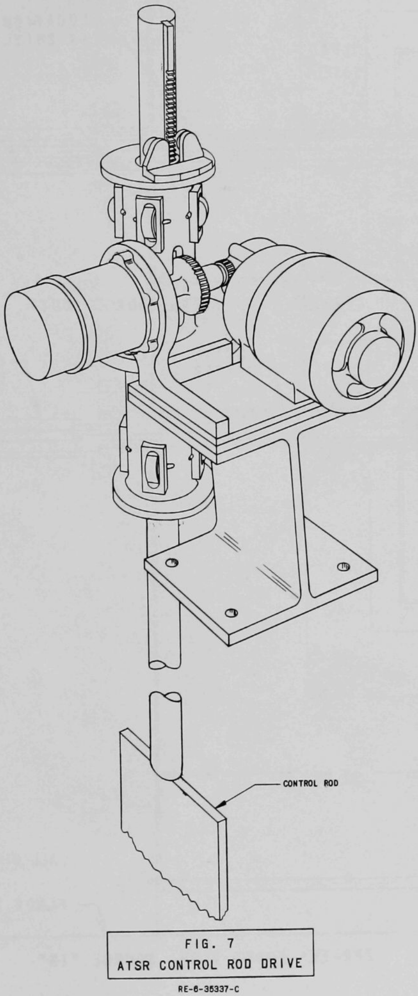


FIG. 7
ATSR CONTROL ROD DRIVE

RE-6-35337-C

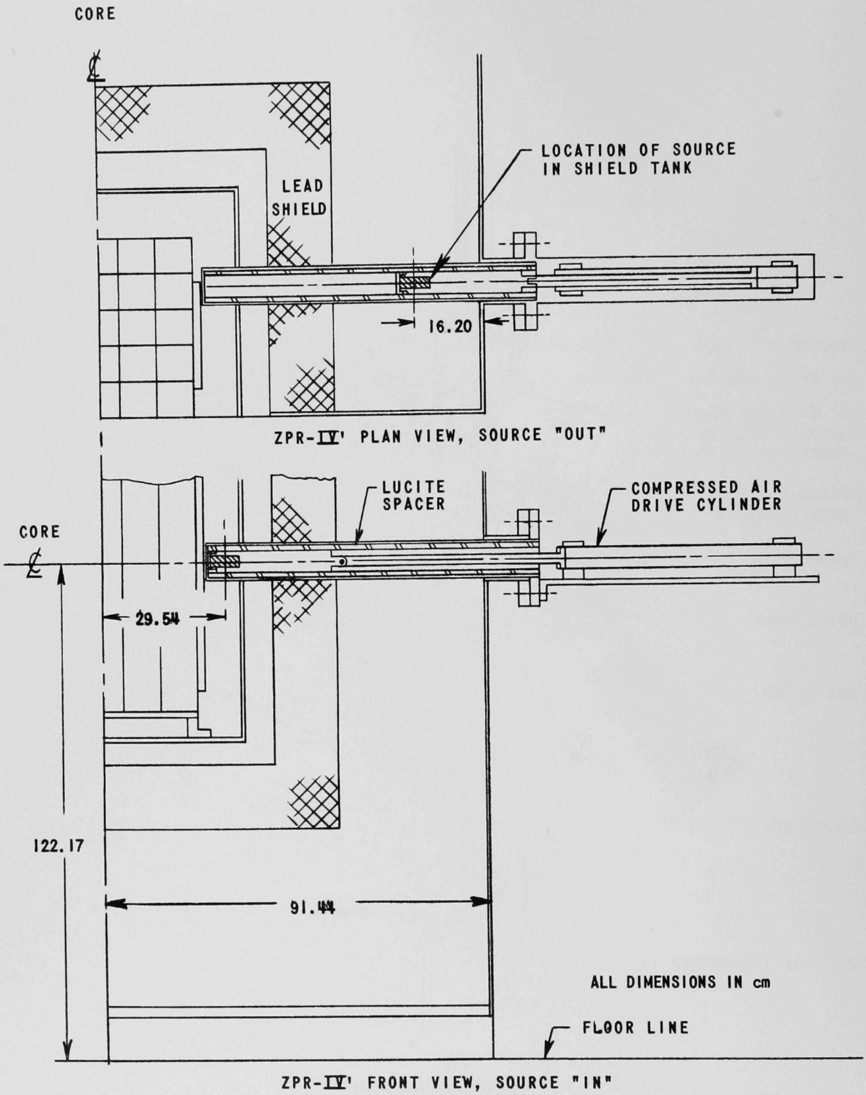


FIG. 8
ATSR SOURCE POSITIONS

(RE-8-36022-B)

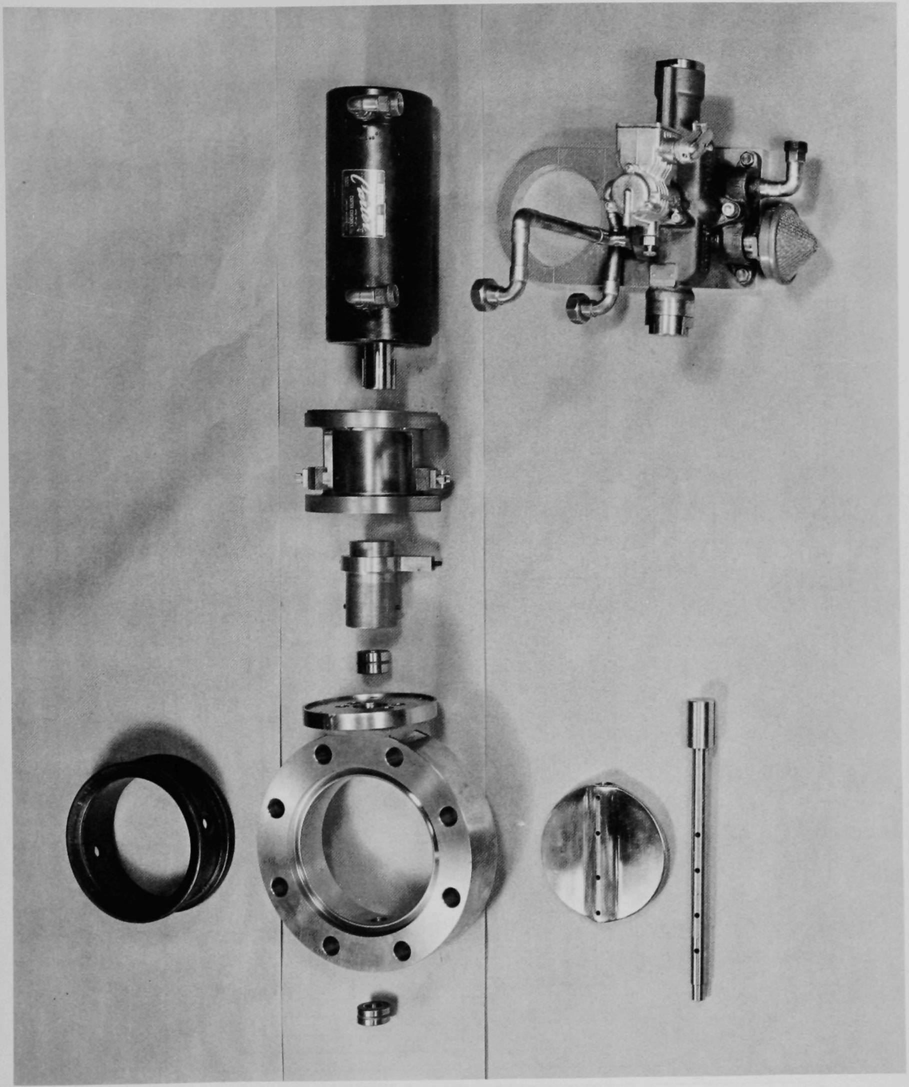


FIG. 9
DISASSEMBLED DUMP VALVE

NEG. NO. 111-8078

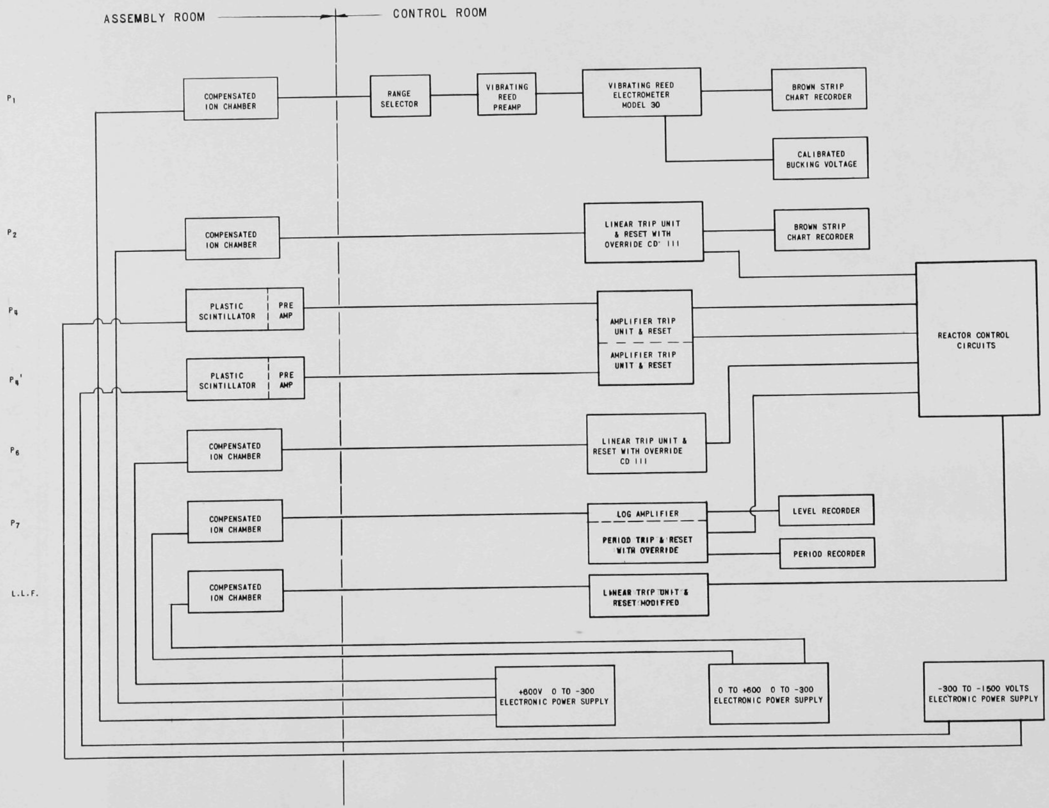


FIG. 10
BLOCK DIAGRAM OF ATSR INSTRUMENTATION

(RE-8-36019-D)

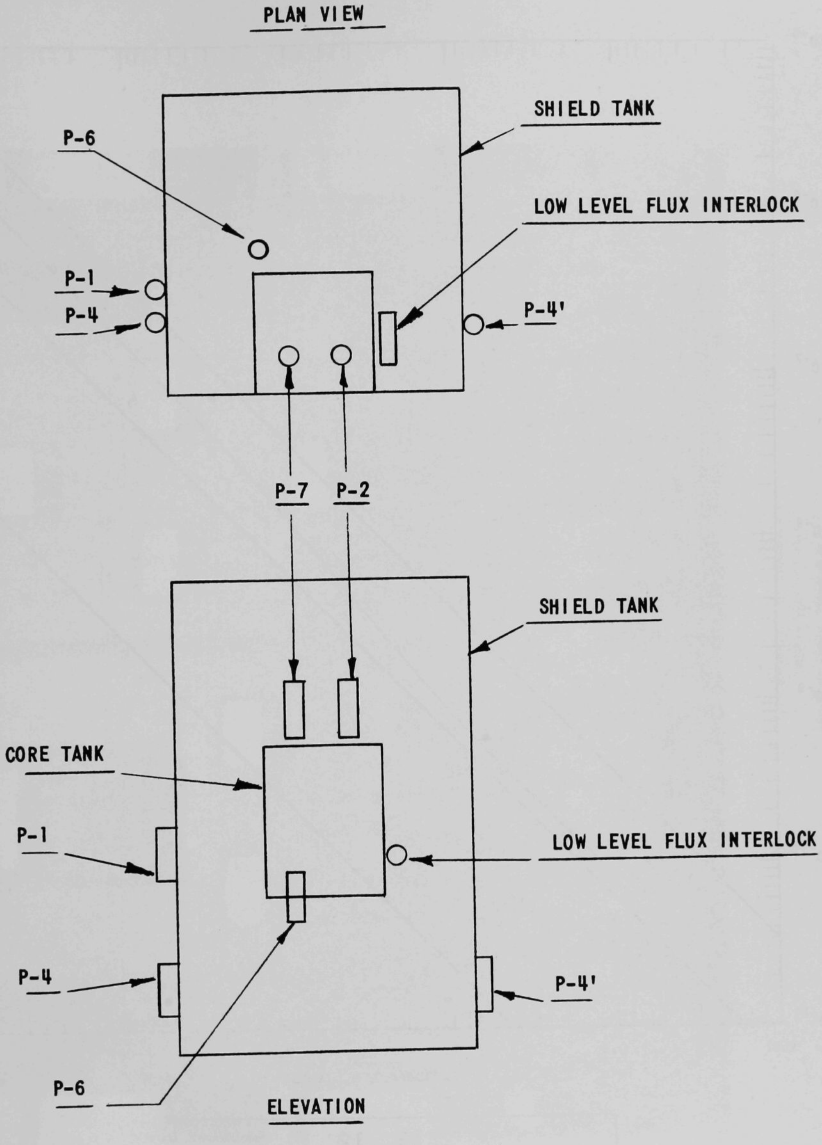


FIG. 11
ATSR DETECTOR LOCATIONS

(RE-8-36020-A)

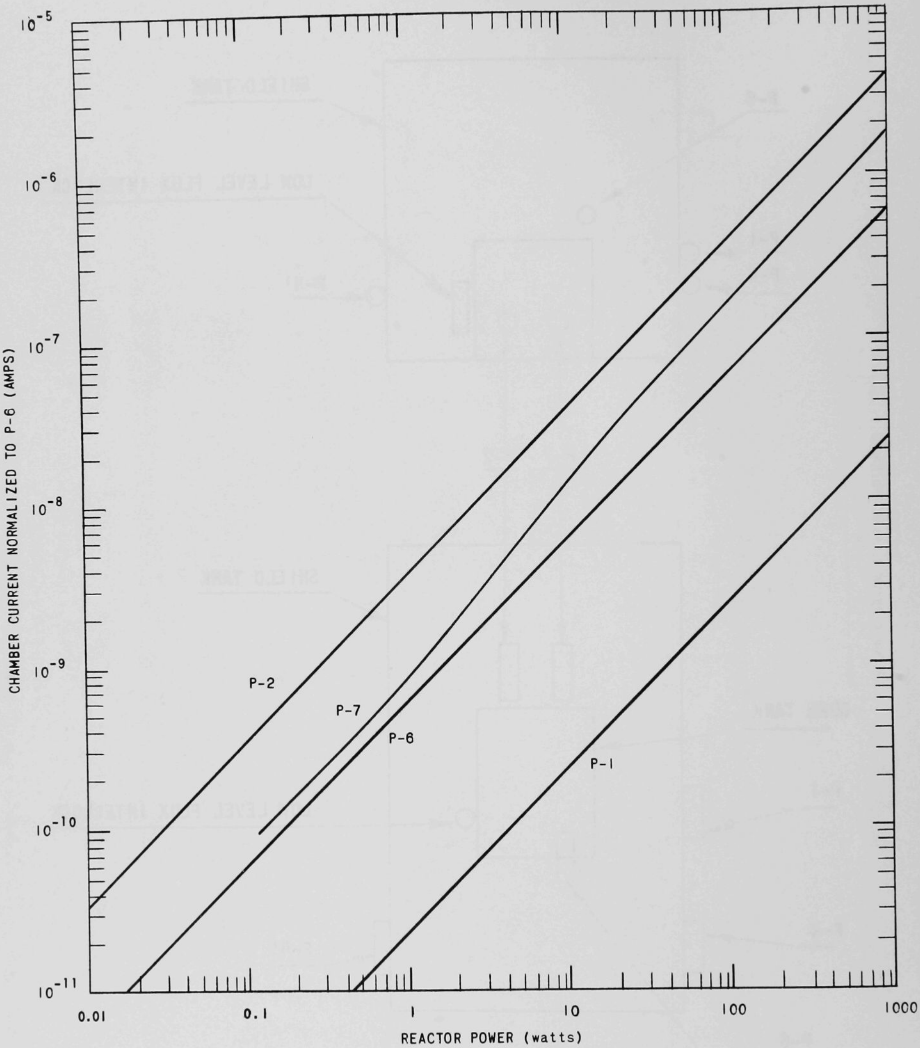


FIG. 12
CHAMBER OUTPUT AS A FUNCTION
OF REACTOR POWER

(RE-7-36018-B)

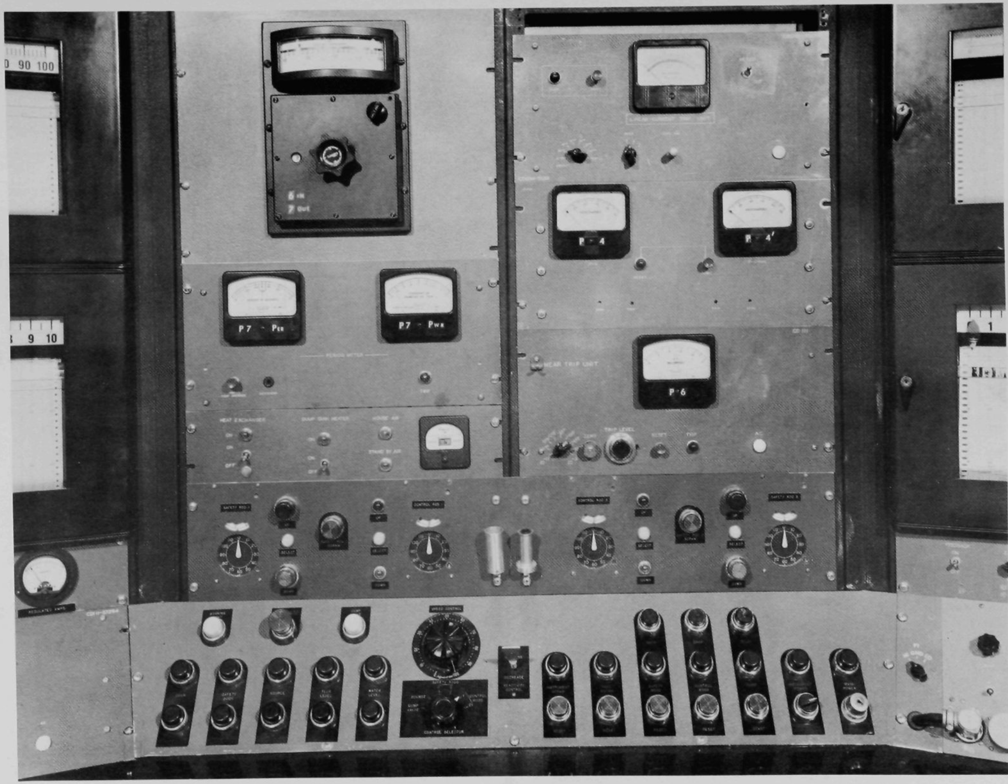


FIG. 13
ATSR CONTROL CONSOLE

NEG. NO. 112-1196

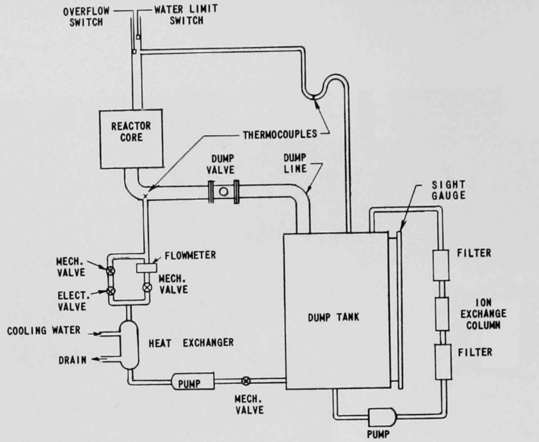


FIG. 14
WATER FLOW DIAGRAM

(RE-8-36023-A)

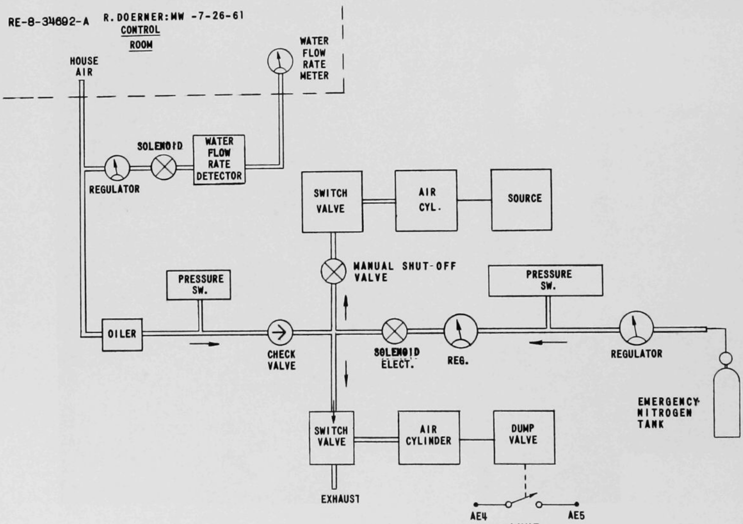


FIG. 15
AIR FLOW DIAGRAM

(RE-8-34692-A)

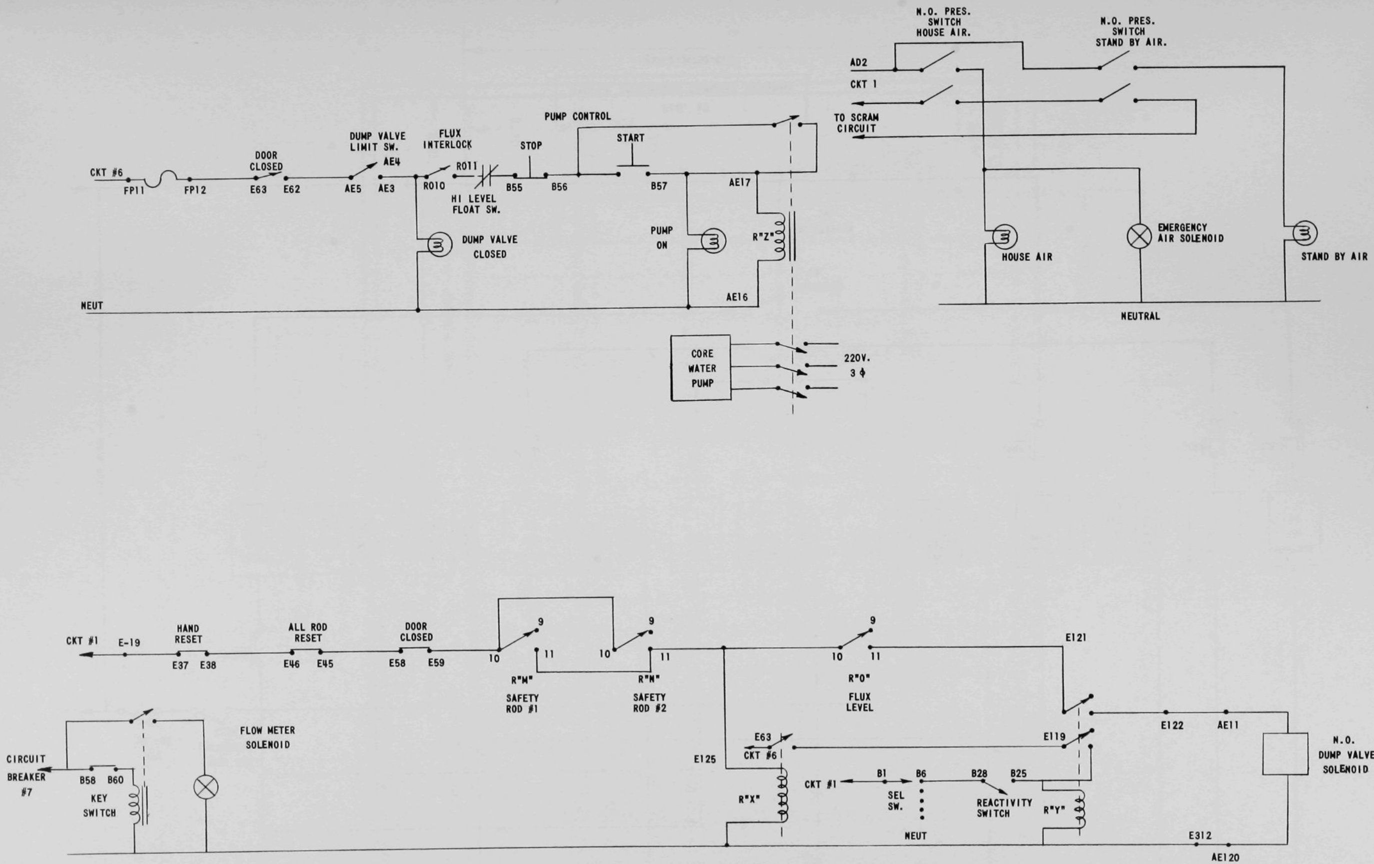


FIG. 18
DUMP VALVE AND PUMP CONTROL CIRCUITS

(RE-2-34701-C)

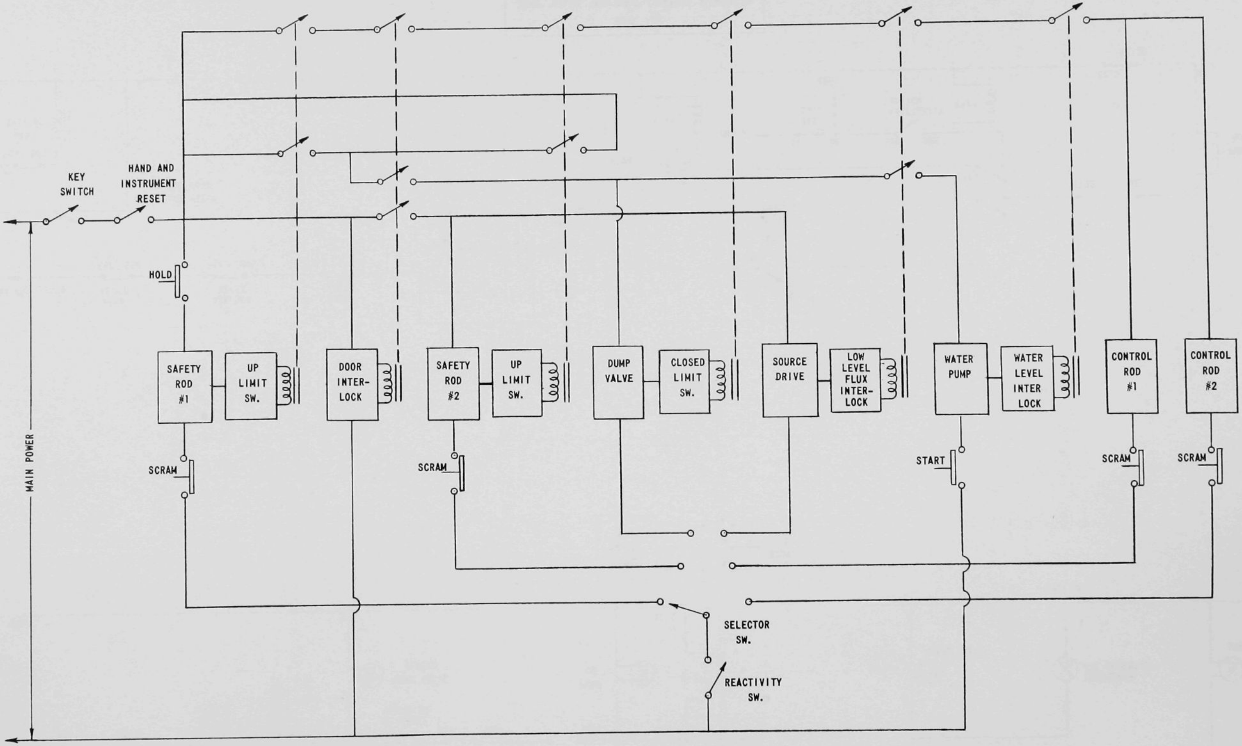


FIG. 17
SIMPLE INTERLOCK CIRCUIT DIAGRAM

(RE-2-34702-C)

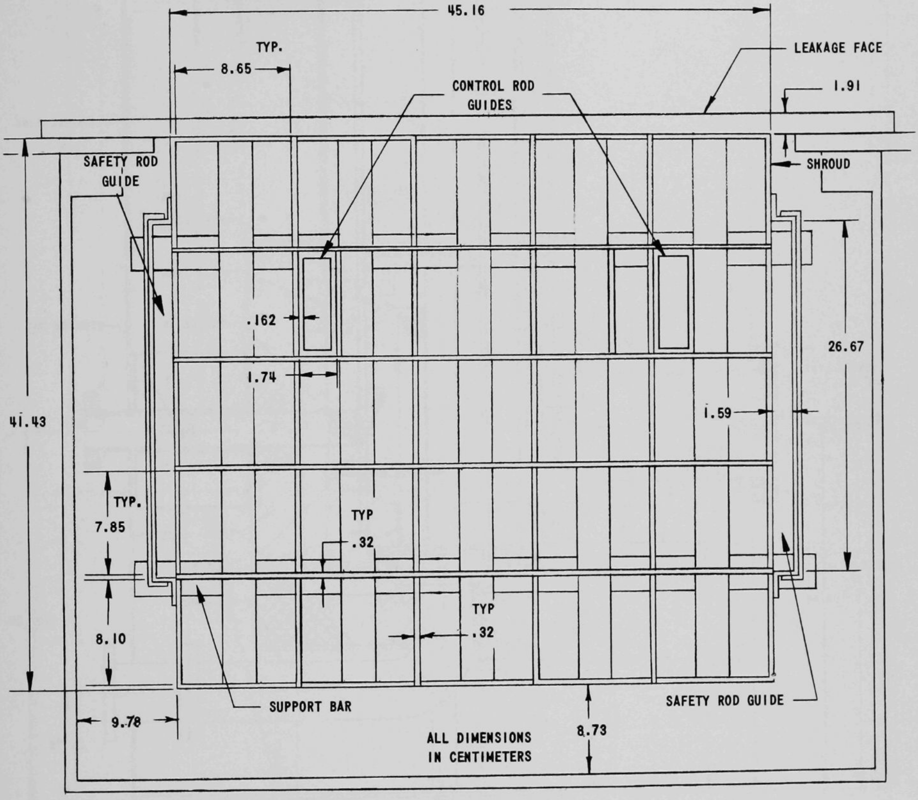


FIG. 18
DETAILED TOP VIEW OF ASTR CORE

(RE-8-36028-B)

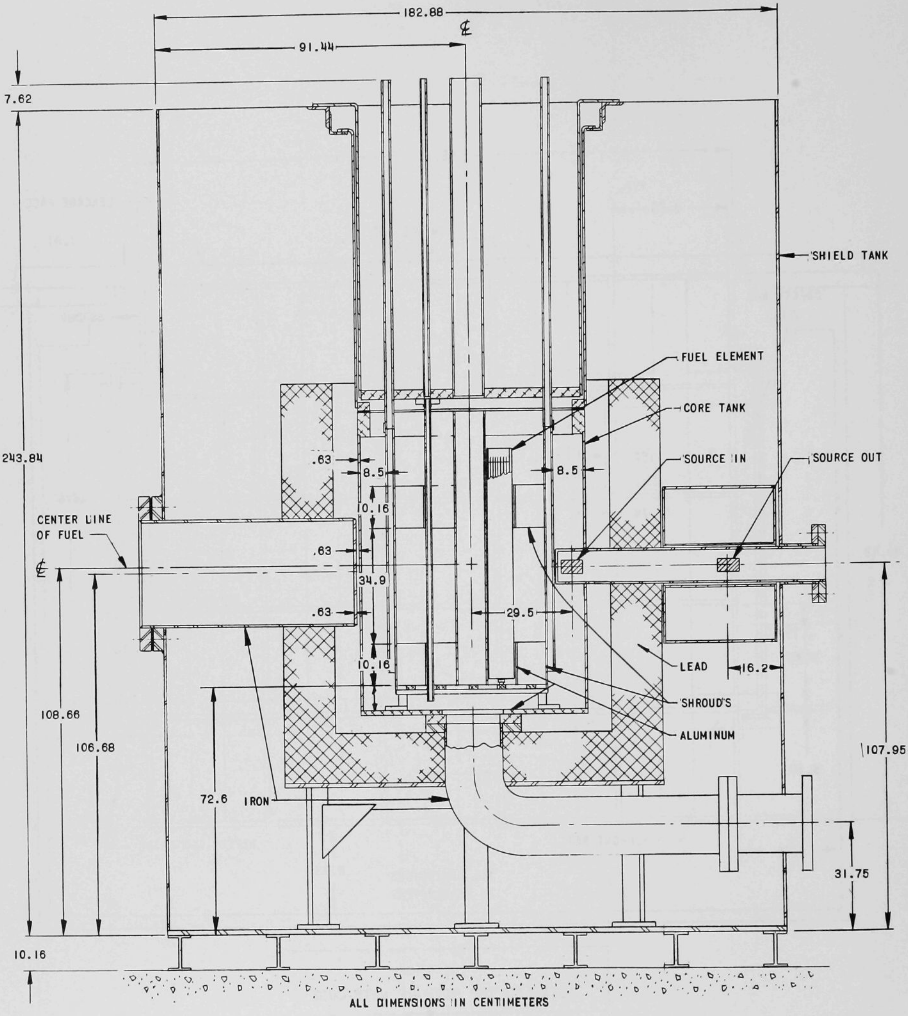


FIG. 19
DETAILED FRONT VIEW OF ATSR CORE

(RE-8-36029-C)

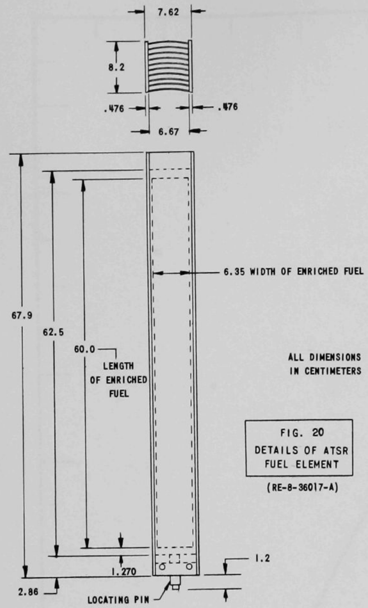


FIG. 20
DETAILS OF ATSR FUEL ELEMENT

(RE-8-36017-A)

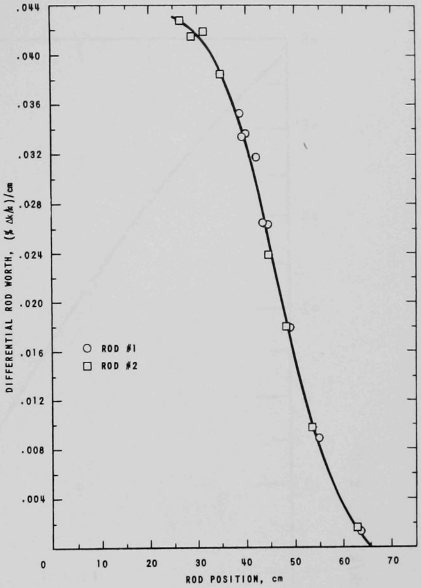


FIG. 21
DIFFERENTIAL ROD WORTH AS A FUNCTION OF WITHDRAWAL

(RE-7-36024-A)

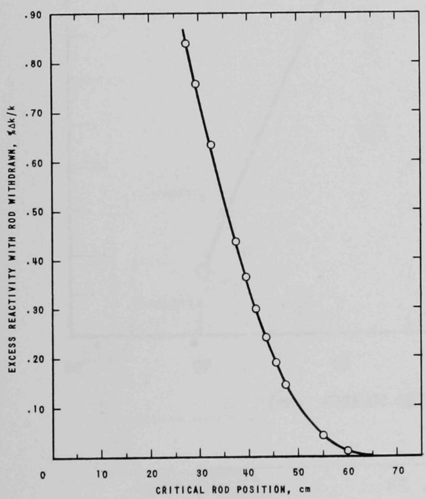


FIG. 22
INTEGRAL ROD WORTH AS A FUNCTION OF CRITICAL POSITION

(RE-7-36025-A)

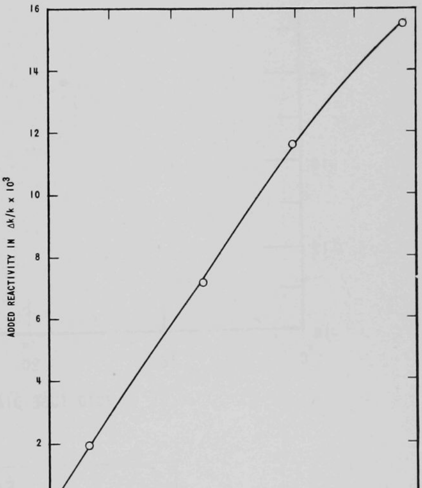


FIG. 23
REACTIVITY AS A FUNCTION OF VOID TUBE SIZE

(RE-7-36015-B)

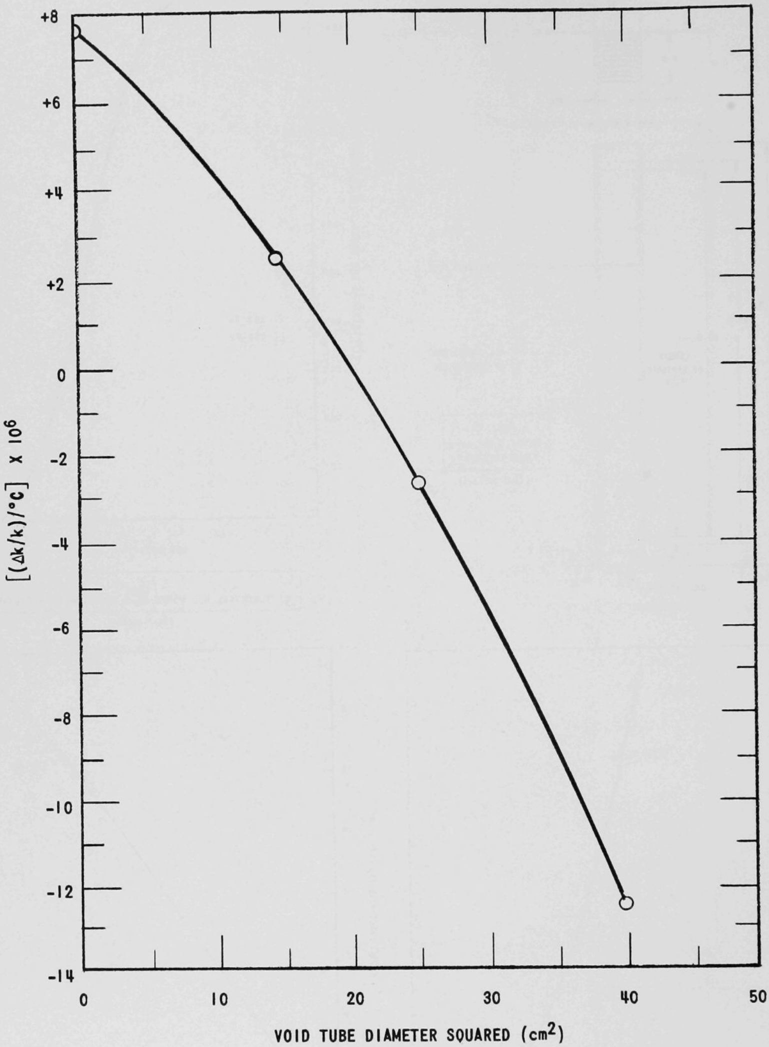


FIG. 24
TEMPERATURE COEFFICIENT AS A FUNCTION OF VOID TUBE SIZE

(RE-7-36026-B)

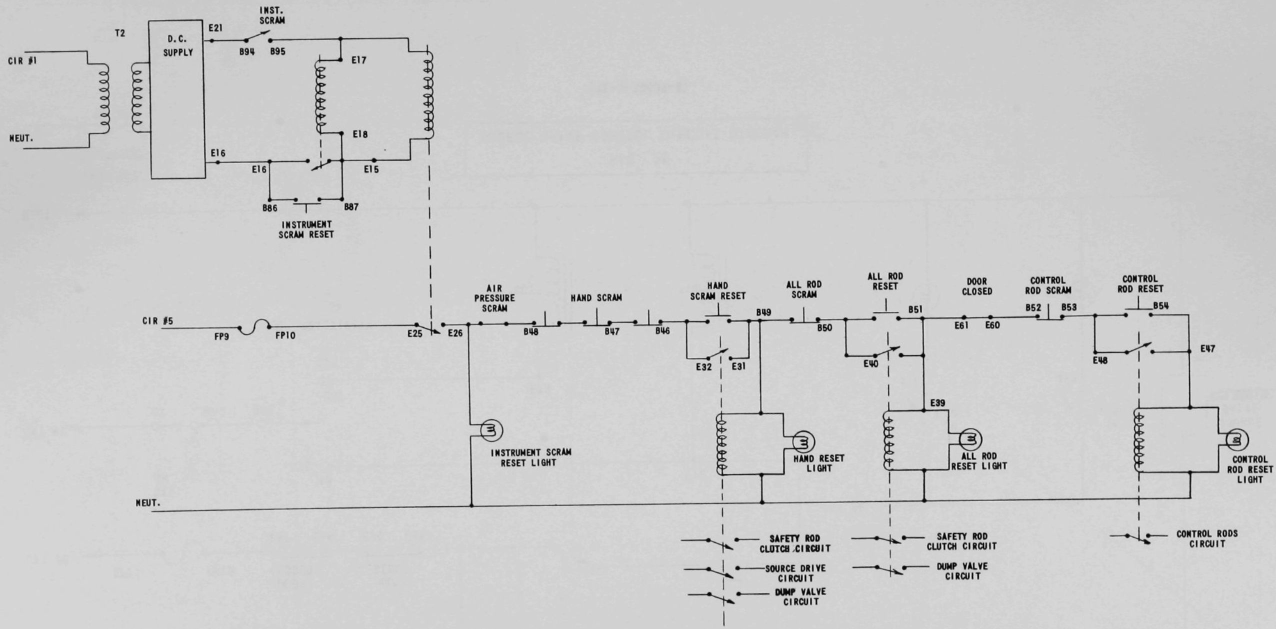


FIG. 26
SCRAM CONTROL CIRCUIT DIAGRAM

(RE-2-34695-C)

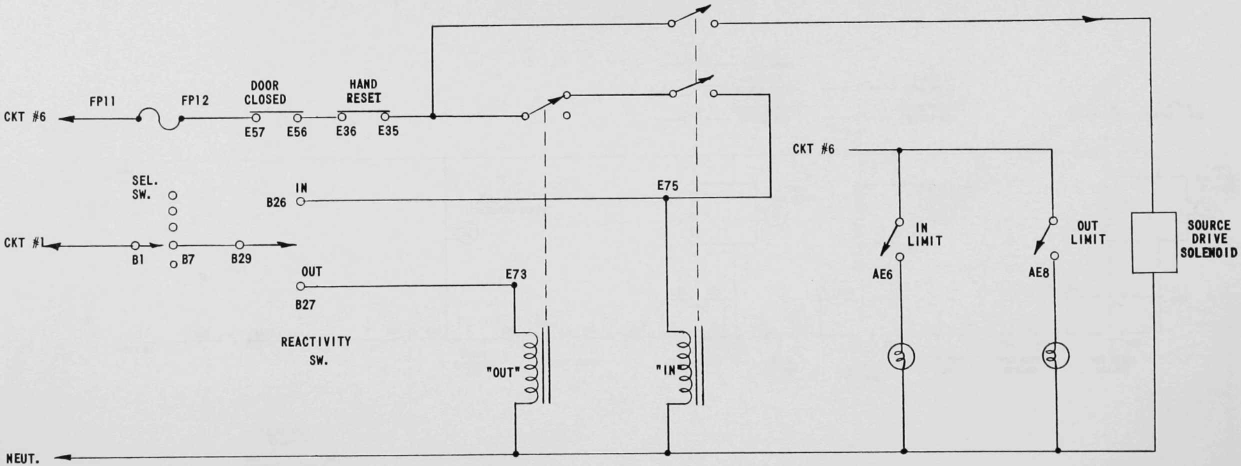


FIG. 26
SOURCE DRIVE CONTROL CIRCUIT DIAGRAM

(RE-2-34694-B)

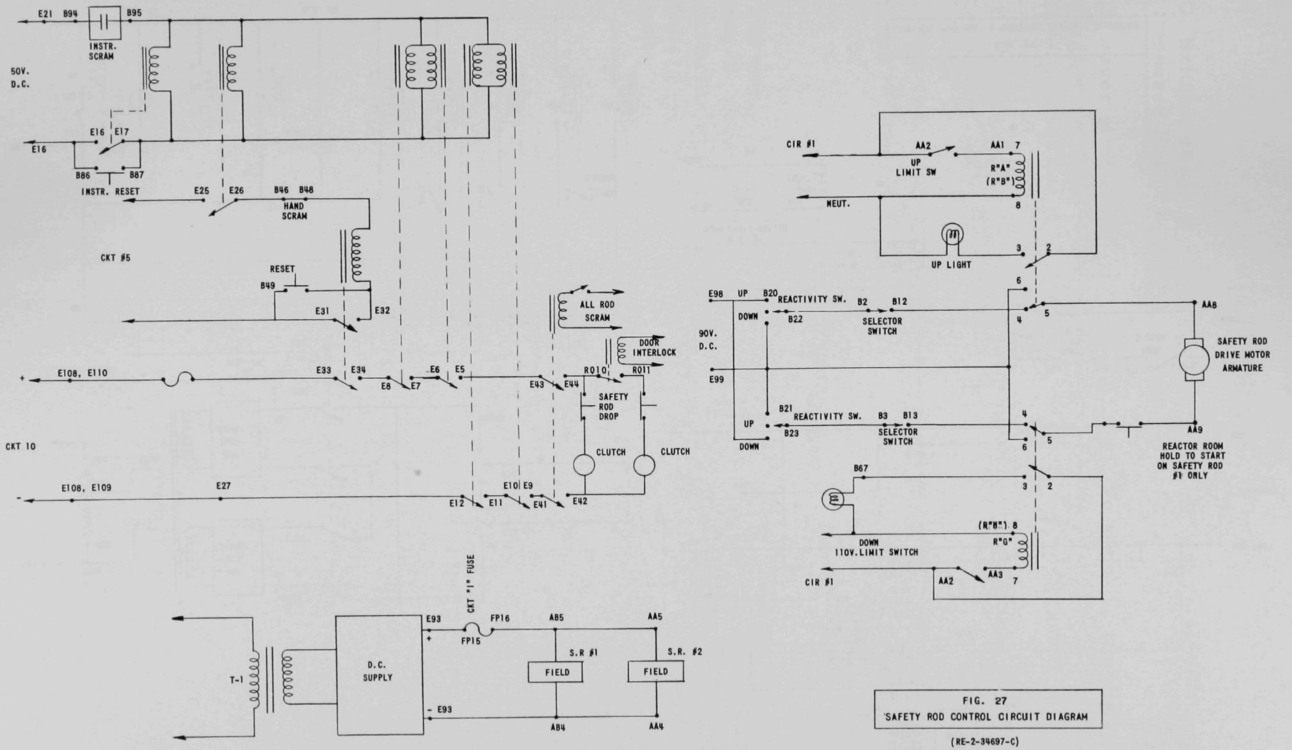


FIG. 27
SAFETY ROD CONTROL CIRCUIT DIAGRAM

(RE-2-34697-C)

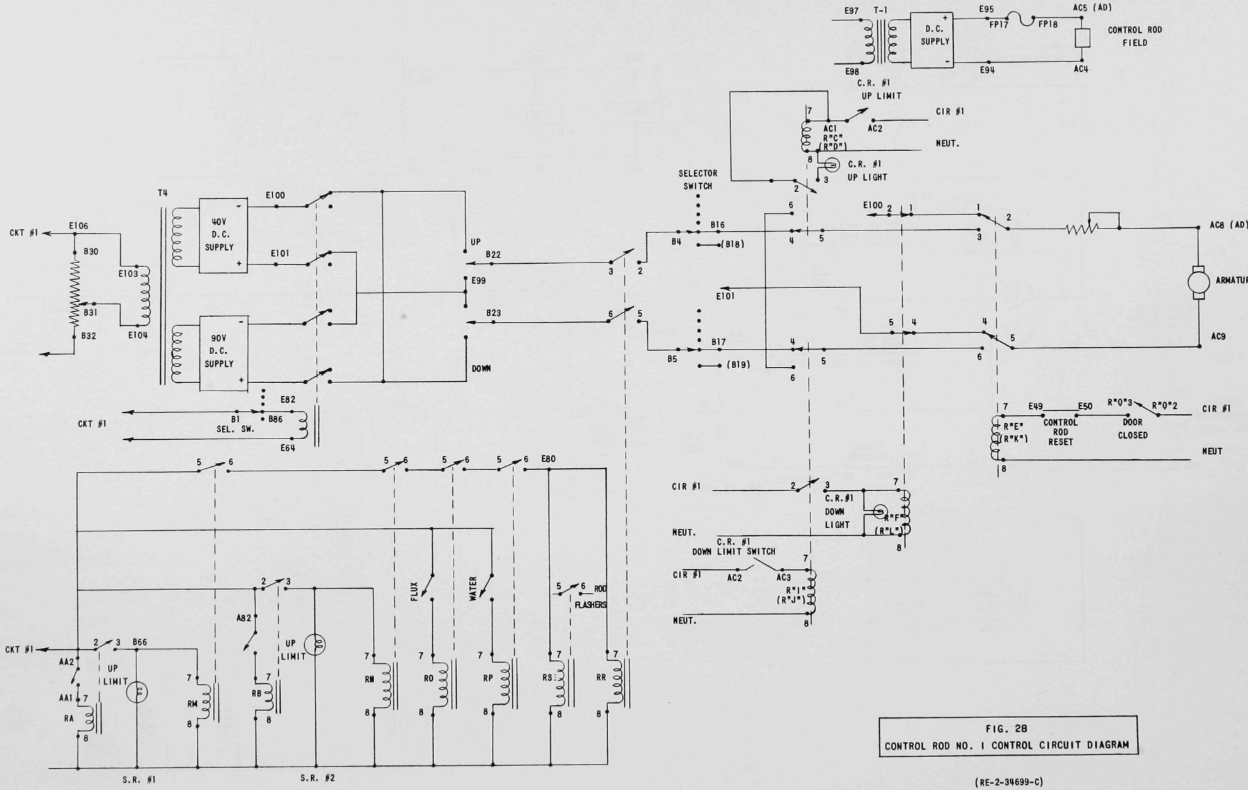


FIG. 28
CONTROL ROD NO. 1 CONTROL CIRCUIT DIAGRAM

(RE-2-34699-C)

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